BUILDING SYSTEMS MODELING AND DESIGN CHALLENGES

Yacine Rezgui, Alexandra Cemesov, and **Christina Hopfe**
Cardiff School of Engineering, BRE Institute in Sustainable Engineering, Cardiff University, Cardiff CF24 3AA.

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Summary

The paper discusses building systems, ways in which these are modeled, and the challenges they present to the research community and stakeholders in the construction sector. A systems thinking perspective is adopted throughout the paper as this is argued to be essential to provide a scientific and engineering foundation for building systems modeling. First, the paper elaborates on the concept of building systems, and then focuses and discusses two fragmented areas that have involved substantial work and research on building systems modeling: Building Information Modeling (BIM) and building systems behavior modeling (or building simulation as commonly known). Critical reflections are then provided and discussed in the context of challenges faced by construction industry stakeholders in their design responses. The paper then argues the need for adapted ontological representations of building systems that factor in structural (including physical properties and geometry) and behavioral aspects of a building. The resulting ontology would provide true (dynamic and holistic) conceptualizations of buildings and their constituent systems in ways that address the constraints of current, and future unknown, scenarios.

1. Introduction

Buildings have often been described as complex entities involving a wide range of stakeholders drawn from a large number of disciplines. This complexity is reflected in the continuous introduction of new procurement paths and methods, construction technologies, materials, and construction methods, to meet various economic, environmental and societal challenges (Rezgui and Miles 2010). Building design requires the involvement of not only the traditional disciplines (Structure, Mechanical & Electrical, etc.) but also many new professions in areas such as energy, environment, waste, and assisted living. For instance, designing a hospital requires not only meeting tighter comfort, energy, health and safety requirements but also reducing drastically infection rates by adapted architectural design responses.

Gidado (1996) argues that complexity in construction can be explained by (a) the resources employed to deliver a building, (b) the natural and physical environment that constitutes the construction site, (c) the increasing level of science and technology involved, and (d) the various forms of interactions taking place between stakeholders across the lifecycle of a building. Two types of complexity emerge: one related to ‘uncertainty’ in terms of dependence on the environment and resources availability as and when needed, and the second relates to the complexity of the design and construction process in terms of workflows and tasks involving inter-disciplinary interventions (Gidado, 1996). Complexity research contends that systems have emergent or synergistic characteristics that cannot be understood without reference to sub-component relationships (Manson, 2001).

Dealing with building complexity necessitates methodological interventions and approaches that factor in multi-disciplinary and multi-faceted perspectives onto common built-environment issues. In that respect, a systems thinking perspective is essential as it provides a foundation for building systems modeling. A systems philosophy demands that an uncoordinated approach is replaced by a framework in which the identities of the separate parts are subsumed by the identity of the total system (Mason-Jones and Towill, 1999). In engineering terms, using a systems engineering approach, the individual systems, subsystems and components of a building are designed and assembled together to achieve a functional and performance driven objective. Furthermore, a building systems thinking approach is necessary to understand how the different components within a building interact, the involved variables, and the dynamic forces that affect their performance.

The paper discusses building systems modeling approaches and associated design challenges. First, the paper elaborates on the notion of building systems and ways in which these are described and classified. In fact, research in building systems tends to be fragmented and spans a wide spectrum of areas, including Building Information Modeling (BIM), Building Physics, Building Simulation, and Construction Management. The paper then focuses and discusses two main but fragmented areas that have involved substantial work and research on building systems modeling: Building Information Modeling (BIM) and Building system physics and behavior. Critical reflections are then provided and discussed in the context of challenges faced by designers in their interventions. A call is then made to provide a holistic and dynamic description of a building and its systems through an ontology which factors in structural (including physical properties and geometry) and behavioral aspects of a building. The paper then provides concluding remarks and directions for future research in building systems modeling.

2. Building Systems

A plethora of models have been developed by a wide range of research communities and disciplines to facilitate the design of the various systems that underpin a building (Rezgui and Miles, 2011). In order to increase their adoption by the wider design communities, these models tend to proceed by simplifying building physical phenomenon and assuming a linear relationship based on a Newtonian mechanistic view of the world (Lu et al., 2010). For instance, simplified physical models are used to calculate building energy performance, taking to a great extent a static, as opposed to real / dynamic, view of the building and its operations (Kolokotsa et al. 2010). However, buildings and their constituent systems have a non linear dynamic nature that is important to understand and model. Buildings are in fact complex systems involving several forms of interactions within and across systems, sub-systems and components which translate into patterns of structure and behavior. The understanding and modeling of these patterns of structure and behavior can only be approached by adopting a holistic view of the building systems as opposed to focusing on analyzing these systems and constituent components individually (Rezgui and Miles, 2011). This is in-line with the systems thinking which can be summarized as follows (Minger and White, 2010):

- *Viewing the situation holistically, as opposed to reductionistically, as a set of diverse interacting elements within an environment.*
- *Recognizing that the relationships or interactions between elements are more important than the elements themselves in determining the behavior of the system.*
- *Recognizing a hierarchy of levels of systems and the consequent ideas of properties emerging at different levels, and mutual causality both within and between levels.*
- *Accepting, especially in social systems, that people will act in accordance with differing purposes or rationalities.*

Hence, buildings consist of dynamically nonlinear interacting systems and components (Trcka, 2008). The scope of Building systems is quite large, it includes the systems that underpin the building (load bearing structure, the various technical services and installations, and their controls), the internal environment in terms of building usage and occupants, and the external environment in terms of site geology, climate, and physical structure of the surrounding built environment. In fact, recent thinking stresses the importance of the notion of the human (i.e. building occupant) being an integral part of the system, as opposed to being considered outside of the system (Lu et al., 2010).

Moreover, building systems modeling needs to factor in the increasing and changing demand of building occupants and ways in which they interact with the various systems that compose a building facility. These occupants will potentially change over the lifetime of a building as this will be subject to different tenants, usages, and transformations.

Moreover, building systems require the consideration of the building in its environment as illustrated in Figure 1. It is important to recognize that a building is a complex dynamic system and to develop the theoretical underpinning that will result in formal information and knowledge structures and methods for their design, construction, maintenance / operation that address the uncertainties of future scenarios as elaborated later in the paper.

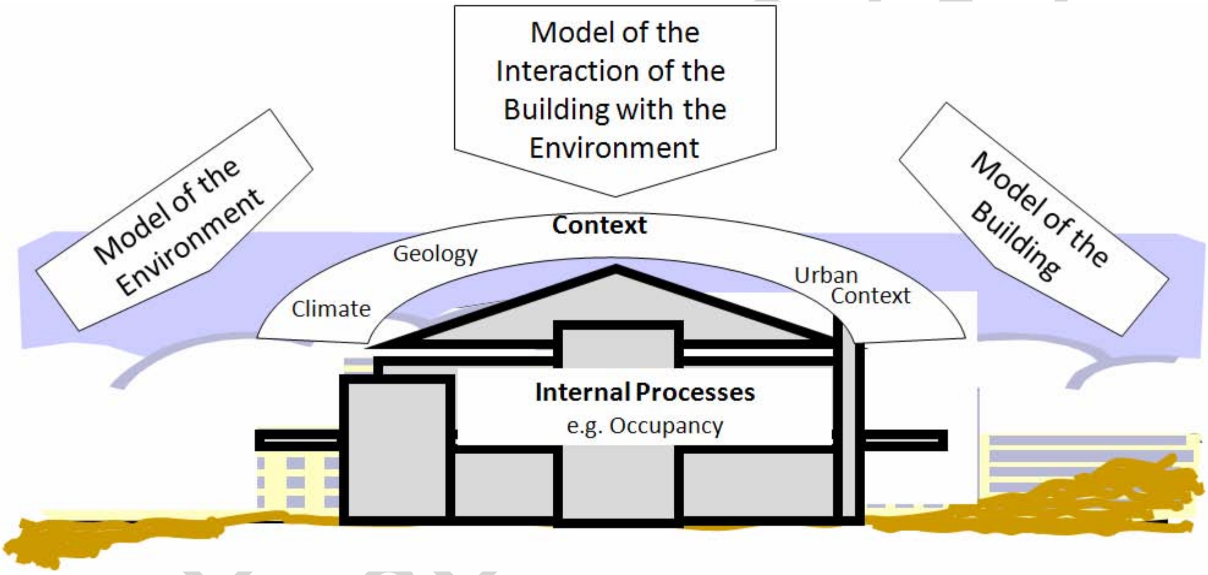

Figure 1. The building in its environment.

Different sources for building systems description can be found in the construction literature (Rezgui, 2007). The Industry Foundation Classes (IFC) take the stance that a system is an ‘*organised combination of related parts within an AEC (Architecture, Engineering and Construction) product, composed for a common purpose or function or to provide a service.*

A system is essentially a functionally related aggregation of products’. More specifically, a building system is defined as ‘*a group by which building elements are grouped to a common function within the building*’ (IFC, 2011). Figure 2 illustrates the recursive relationships between systems, each of which (system) resulting from a functional association of components or parts.

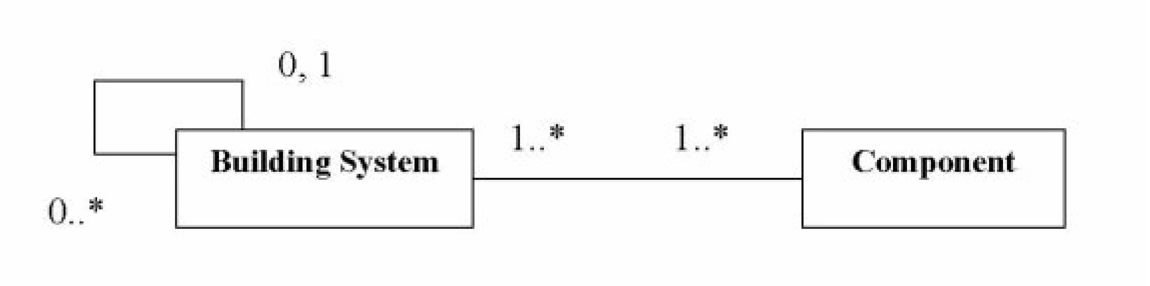

Figure 2. Conceptual illustration of a building system.

Another source for building systems description is Uniclass (Crawford et al., 1997), a classification system that provides a comprehensive description and classification of the systems that underpin a construction facility. It has increasingly been gaining acceptance in the construction industry (Rezgui, 2007).

It was first published in 1997 as a substitute for CI/SfB (Ray-Jones and Clegg, 1976). Similarly to CI/SfB, Uniclass is structured with a faceted classification system that involves a hierarchical description of facets for detailed items classification.

Differently from CI/SfB which focuses on architectural projects, Uniclass focuses on both architectural works and civil engineering works by including classification facets to cover the following:

- Common Arrangement of Work Sections (CAWS) - used for architectural works;
- Electronic Product Information Co-operation (EPIC) – used for product's data and literature classification;
- Civil Engineering Standard Method of Measurement (CESMM) – used for operations classification in quantity surveying for civil engineering works.

Uniclass consist of 15 tables, each of which corresponds to a different main facet of construction information (Table 1).

Facets	**Characteristics of items**	**Purposes**
A. Form of information	Features of information	Organizing general reference information
B. Subject disciplines	Fields of knowledge	Reference material related to theory
C. Management	Processes with purpose of management	Information concerning all aspects of management
D. Facilities	Construction complexes	Classification of construction facilities

E. Construction entities	Independent constructions	Classification of physical forms or functions in facility (civil engineering projects)
F. Spaces	Independent constructions	Classification of physical forms or functions in facility (architectural works)
G. Elements for buildings	Main physical parts of independent constructions	Classification of elements in space (architectural works)
H. Elements for civil engineering works	Main physical parts of independent constructions	Classification of elements in construction entity (civil engineering works)
J. Work sections for buildings	Physical parts of element	Classification of operations (civil engineering works)
K. Work sections for civil engineering works	Physical parts of element	Classification of operations (architectural works)
L. Construction products	Products or components for incorporation into operation	Technical information for construction products
M. Construction aids	Construction material resources	Itemizing trade literature and information about equipment
N. Properties and characteristics	Attributes and other factors concerning physical objects	Classification of subjects relating to projects
P. Materials	Substances and material	Classifying resources from which construction products, elements, or entities may be made
Q. UDC	Connection of items with UDC	Classifying subjects of UDC

Table 1: Structure of Uniclass Facets, Source: CPIP (1997).

Table 2 illustrates a breakdown description of “disposal systems” used to transport solids and liquids away from inhabited areas, so they can be treated or discharged in a place that does not affect public safety.

JR - Disposal Systems	JR1 - Drainage	JR10 Rainwater drainage systems
		JR11 Abode ground foul drainage systems
		JR12 Below ground drainage systems

		JR13 Land drainage systems
		JR14 Laboratory and industrial waste disposal systems
		JR16 ground water pressure relief drainage
		JR17 Soakaways, septic tanks and sewage treatement plant
		JR18 Pumping stations and pressure pipelines
	JR2 - Sewerage	JR20 Sewage pumping
		JR21 Sewage treatement and sterilisation systems
		JR23 Sewage treatement systems
		JR24 Constructed wetlands
	JR3 - Refuse Disposal	JR30 Centralised vacuum cleaning
		JR31 - Refuse chutes
		JR32 - Compactors/Macerators
		JR33 - Incineration plant
	JR9 - Domestic disposal	JR90 - Waste disposal systems - domestic
		JR91 - Refuse disposal systems - domesti

Table 2: A breakdown of the subitems in the disposal systems category of Uniclass, Source: CPIP (1997).

A comprehensive description of the Uniclass classification of building systems can be found in (Crawford et al., 1997). This is relayed by several web sites maintained by construction related institutions, including www.cpic.org.uk.

As noted earlier, research in building systems tends to be fragmented and spans a wide spectrum of areas. The following two chapters will focus on and discuss two main areas that have attracted substantial research on building systems, namely building information modeling and building simulation.

While the former (BIM) models a building as a static entity for information sharing purposes, the latter aims at providing dynamic accounts of building systems behavior.

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Biographical Sketches

Professor Yacine Rezgui is an architect with a PhD in Computer Science. He currently directs the BRE (Building Research Establishment) Institute in Sustainable Engineering at Cardiff University. His research factors in latest developments in digital technologies and smart homes and addresses key challenges faced by our built environment. He has over the last 15 years developed solutions to (a) support collaboration and cooperation needs of (global) virtual teams across the lifecycle of a construction project, (b) promote effective knowledge management, value creation and sustainability in organizations and on projects, and (c) provide total lifecycle information models with a view of delivering a dynamic and self-updating digital representation of a building. His current work focuses on delivering smart buildings adaptable to their use and environment that fully exploit latest pervasive sensing technologies, white goods, and smart building components. He has published over 150 “refereed” papers in the above areas, and has completed over 17 research and development projects, funded by national and European research councils, in collaboration with leading organizations across Europe.

Alexandra Cemesova graduated in 2010 from Cardiff University with a degree in Architectural Engineering. Currently, she is undertaking a PhD in the field of the future adaptability of buildings. Some factors that are necessary to examine are how a building reacts to a changing climate and function over its lifecycle. This will involve examining how integrating building information modeling and building performance simulation can help us design and analyze buildings more effectively over their lifecycle.

Dr Christina Hopfe has a degree in civil engineering and graduated 2005 at Technical University in Darmstadt, Germany with major in finite element theory and object oriented programming. During her studies she gained already working experience whilst conducting diverse projects in consulting agencies and software development companies, among others. After graduating, Christina started her Ph.D. research in the Building Physics and Systems group, at the Department of Architecture, Building, and Planning, Eindhoven University of Technology, The Netherlands. During her PhD studies, Christina spent several months at the Georgia Institute of Technology in Atlanta, Georgia (2007/ 2008). She is presently a Lecturer in Engineering Informatics at Cardiff University.